THE STRUCTURE AND EVOLUTION OF SQUALL LINE AND BOW ECHO CONVECTIVE SYSTEMS

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REFLECTIVITY CHARACTERISTICS:

1. During bow echo incipient stage, strong downburst may descend within or on rear flank of convective echo, resulting in an initial bulging echo pattern.

2. Bulging/bowing of reflectivity gradient forward/downwind from rest of squall line. Usually strong low-level reflectivity gradient present on leading edge of intense convection indicating strong convergence and vertical updraft.

3. Subtle weak echo regions (WERs) may be present on leading edge of reflectivity gradient marking location of significant storm-relative inflow and updraft zone.

4. Rear inflow notches (RINs)/weak echo channels (WECs) sometimes noted behind leading intense convection, which usually are co-located with local enhancements in rear inflow jet (RIJ).

5. Within overall serial-type squall line, may be several bowing echo segments embedded.

6. Bow echoes often associated with significant damaging surface winds (assuming well-mixed boundary layer) near apex of bow (along RIJ), and possible non-supercell/shear vorticy tornadoes along or north (cyclonic side) of apex.

7. Leading line remains intense if low-level cold pool beneath convection balances ambient vertical wind shear, so that outflow boundary and intense updrafts remain on leading edge of convective line. Outflow boundary propagating ahead of line may initiate new cells downwind but will eventually diminish updrafts and intensity within main line.

8. May or may not be relatively large "stratiform" precipitation area (albeit still some thunder and lightning) behind leading convective line depending on amount of storm-relative elevated front-to-rear flow. Serial-type "cool season" squall lines usually are associated with more training stratiform precipitation than progressive "warm season" events.

VELOCITY CHARACTERISTICS:

1. Mid-altitude radial convergence (MARC) signature sometimes evident in WSR-88D storm-relative velocity map (SRM) data at altitude of about 3-7 km. Strong (over 50 kts; 25 m/s), persistent, deep-layered MARC ($V_{in} + V_{out}$) within area of convection can signify entrainment of environmental air that enhances negative buoyancy and results in downdraft acceleration, i.e., a downburst. This causes onset of damaging surface winds and development of low-level bow structure in reflectivity data.

2. Local enhancements in rear inflow jet (RIJ) tend to develop along and behind axis of bowing line segments, especially those associated with significant trailing stratiform precipitation. Convective downdrafts/outflow can intensify wind flow and damage associated with RIJs.

3. If ambient wind shear is moderate-to-strong, RIJ tends to remain elevated up to near leading edge of bow echo, then rapidly descends at updraft/downdraft interface causing significant wind damage.

Systems with elevated RIJs usually longer-lived with rapid multicell growth along leading edge.

4. If ambient shear is weak, RIJ tends to descend gradually and spread out along and behind leading line, still with possible wind damage but less intense/shorter-lived than for stronger sheared MCSs.

5. Squall lines often contain two main airflow streams relative to moving convective system. First stream is rear-to-front associated with the RIJ. Above this stream is storm-relative front-to-rear flow. This stream has warm, moist origins ahead of squall line, rises up rapidly within leading convection, then exhibits much more gently sloped ascent behind line resulting in trailing stratiform precipitation.

MESOCYCLONE CHARACTERISTICS:

1. Cyclonic circulation (mesocyclone) formation and possible tornadogenesis within squall lines usually occur in association with bowing line segments given sufficient forcing, instability, and wind shear.

2. For leading line (bow echo) tornadoes, initial circulation typically develops as area of enhanced cyclonic-convergence in lower portions of storm along/just north of bow apex, then rapidly intensifies and deepens in altitude, partly due to rapid vertical stretching in updraft. Circulation may be wrapped within moderate-to-heavy precipitation. Vortex eventually broadens and weakens as it propagates rearward with respect to leading line. Tornado occurrence most likely during intensifying and deepening stage, when tight shears and strongest rotational velocities exist.

3. Tornadoes sometimes tucked within subtle weak echo region (WER) on front forward flank of organized bow containing HP supercell characteristics. Tornadoes also can occur within moderate-to-heavy precipitation under rapidly rotating comma head reflectivity signature.

4. Convective boundary interactions with bow echoes may further enhance convergence and vertical stretching allowing for more rapid development and spin-up of mesocyclones/cyclonic circulations.

5. Vortex evolution along organized, long-lived bow echo can be cyclic, i.e., initial circulation develops and intensifies, propagates along bow, and eventually weakens. However, new circulations can develop quickly along bow apex and go through same life cycle. This can result in series/family of transient tornadoes.

6. Tornadoes associated with bow echoes frequently are relatively short-lived and usually of F0-F2 intensity. Tornadic damage usually embedded within and/or on northern fringe of maximum straight-line wind damage associated with bow apex and rear inflow jet. Large majority of damage from bow echoes is from straight-line winds.